ECONOMIC IMPACTS OF U.S. OIL REPLACEMENT POLICIES: METHODOLOGY AND RESULTS FOR THE OTA ANALYSIS

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This paper describes the methodology and detailed results supporting the conclusions in Chapter 4, "Economic Aspects of an Oil-Replacement Strategy," which will appear in a forthcoming Office of Technology report on the potential for replacing oil.

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Introduction

This paper discusses the likely economic impacts of two different OTA scenarios: (1) a major oil disruption lasting five years, and (2) a major disruption with an accelerated U.S. oil replacement policy. Each case is compared with a baseline scenario depicting stable oil market conditions without an accelerated oil substitution policy. The analysis addresses three central issues: (1) the effect of a major disruption on oil prices, (2) the effect of an aggressive US oil-replacement policy on mitigating the oil price shock during a major disruption, and (3) the effects of these oil price changes on the U.S. economy. Our analysis is based upon a number of studies of these issues, including several EMF studies. Impacts on the oil price and on the economy are derived for two time periods--two years and five years after the disruption.

At OTA's request, we did not conduct extensive modeling of these issues, in order to complete the analysis in a timely fashion. Nevertheless, the analysis suggests the approximate impacts that one might expect to obtain from a more comprehensive modeling of the key energy and economic relationships, had there been sufficient time for such an effort.

Baseline Conditions

For our initial analysis, we have used the following baseline conditions that appear representative of recent Energy Information Administration (EIA) forecasts as reported in their International Energy Review. The annual EIA forecast has not been released since the Iraqi invasion of Kuwait last August. Accordingly, we have modified the initial 1990 conditions while maintaining the basic flavor of the projected trends in these earlier forecasts. Oil prices in our baseline hold steady at $22 per barrel over the next five years, thus coinciding with the 1995 estimate in the EIA's 1990 base projection. World oil consumption grows by 1% p.a. from 52 MMBD in 1990, while Non-OPEC production holds steady at 29 MMBD. OPEC production meets the residual demand. Within the

U.S., consumption grows by 1% p.a. from 17 MMBD in 1990 and production declines by 1% p.a. from 9 MMBD in 1990. US imports grow by the difference between US consumption and production.

These assumptions are summarized in Table 1. OPEC's share of market economies' consumption reaches 44% by the second year and 47% by the fifth year. US imports grow from 8 MMBD to 8.5 MMBD by the second year and to 9.3 MMBD by the fifth year.

Disruption Size

Since oil is a fungible commodity, the relevant concern for all economies (including the U.S.) will be the share of world oil production lost during the disruption. All economies face the same increase in oil prices, which will be governed by this share and several key supply and demand responses to price. The U.S.'s dependence upon oil imports will not directly determine how high oil prices must move or the effect of a U.S. oil-replacement policy on oil prices.

This situation means that the economic impact of a disruption must be determined from world rather than U.S. oil market conditions. It is assumed that all of the 16 MMBD of Persian Gulf oil is lost to the world market for an extended period of 5 years. The lost production represents a 30% shortfall for a world oil market using 53 MMBD in the second year, although it will be partly offset by the increase in world oil supplies from Non-OPEC regions induced by the higher prices of the sustained disruption. Accordingly, the US economy will share proportionately in this world shortfall of 30%, unless supply and demand responses to prices vary significantly across countries. We estimate that an initial 16 MMBD disruption removes about 4.0 MMBD of oil from US economies, after accounting for the production offsets from supply regions outside OPEC.

The price increase required to overcome this shortfall and rebalance the oil market will depend upon both the size of the shortfall and how quickly this shortfall is eliminated by higher oil prices.

This price impact is estimated as the share of world oil consumption lost during the disruption, divided by an elasticity that incorporates four responses: (1) the effect of higher prices on world oil consumption, (2) the effect of higher prices on world oil production (outside the Persian Gulf), (3) the effect of higher prices on world economic output (GNP), and (4) the effect of lower economic output on world oil consumption. Table 2 contains representative values for these key parameters for the two time periods, based upon several EMF studies comparing models of the world oil market and of the U.S. economy.

The lost oil production and its effect on oil prices for the disruption scenario are summarized in the first two columns of Table 3. There exists considerable uncertainty about any estimate of how high prices would reach during a disruption. Nevertheless, these estimates are representative of what other analysts have estimated for similarly sized oil disruptions.

The sustained disruption would push oil prices from $22 in the baseline to about $50 after two years and to about $44 after five years. Prices in the very short run, of course, could be considerably higher, particularly since these estimates ignore such issues as oil trading and stockpiling dynamics. The percentage increase in oil prices in the second year, for example, is calculated by dividing the 30% net shortfall by a "total" impact elasticity of .24. (Note: See Appendix and Table A.1 for qualifications of these results.)

The US Oil Replacement Policy

A second scenario combines the sustained disruption with an aggressive US policy towards replacing oil use. The policy is assumed to reduce U.S. oil use by 1.4 MMBD at any oil price in the second year and by 3.0 MMBD in the fifth year. Furthermore, it is assumed that the policy does not displace any oil consumption that would ordinarily be curtailed as a result of the higher prices of a disruption. This assumption gives the oil replacement policy its most favorable impact on oil prices.

Table 1: Assumed Baseline Conditions

	2nd	5th
Oil Price	22.0	22.0
WOCA Consumption	53.0	54.7
OPEC Production	24.0	25.7
OPEC Share	45.3%	47.0%
US Consumption	17.3	17.9
US Production	8.8	8.6
US Imports	8.5	9.3

Table 2: Assumed Price Elasticities

	2nd	5th
WOCA Demand	0.15	0.20
OPEC Supply	0.00	0.00
Non-OPEC Supply	0.10	0.15
WOCA GNP Loss	0.04	0.02
Total Impact#	0.24	0.30
US Demand	0.15	0.20
US Supply	0.10	0.15
US GNP Loss	0.04	0.02

#This elasticity is the sum of the demand and GNP elasticities plus a weighted (by market share) average of the OPEC and Non-OPEC supply elasticities. The demand elasticity of income is assumed to be unity.

Table 3: Disruption Size and Oil Price Impacts

	Sustained Disruption		Disruption with Accel. Replacement	
	2nd	5th	2nd	5th
World Disruption	16.0	16.0	16.0	16.0
US Relacement Policy	0.0	0.0	1.4	3.0
Net World Shortfall	16.0	16.0	14.6	13.0
% of WOCA	30.2%	29.3%	27.5%	23.8%
Oil Price Increase	125.8%	97.5%	114.8%	79.2%
Disrupted Price	$49.7	$43.5	$47.3	$39.4

As shown in the last two columns of Table 3, the oil replacement policy causes the world oil price not to rise as much as in the initial scenario. As with the disruption, these effects must be calculated from world oil rather than U.S. market conditions because of oil's fungibility. We calculate the oil price with an approach analogous to the disruption case. The policy of replacing 1.4 MMBD of U.S. oil use reduces the net world shortfall of the disruption to 14.6 MMBD, or about 27.5% of world baseline consumption of 53 MMBD in the second year. Using the same "total" impact elasticity as above, we calculate oil prices after two years to be approximately 115% higher than in the baseline--$47 rather than $22. Relative to the disruption case, the US policy reduces the price shock by $2.40 after two and by about $4 after five years.

Changes in Real GNP

Higher oil prices reduce aggregate economic output in both the short and long run. Due to rigidity in prices and wages, the oil price shock causes the aggregate price level within the economy to rise temporarily. If the supply of money is held unchanged (perhaps due to inflationary fears), interest rates will tend to rise, curtailing first investment and then additional spending associated with that direct investment through the multiplier effect. Domestic spending may also be lessened through losses in real wealth. Over the longer run, higher oil prices can reduce full-employment output by reducing the productivity of labor and capital.

The mechanisms through which oil prices can affect the economy are numerous and are best represented by a fully articulated model of the national economy. Here, we provide several benchmark estimates of the impact through the use of a single parameter linking oil price changes with declines in real GNP. Table 2 contains representative values for that parameter, based upon an EMF study of the macroeconomic impacts of energy price shocks. Since oil expenditures as a share of GNP is currently about 40% of its share in 1983 (when the EMF study was conducted), the earlier EMF estimates of these elasticities have been scaled down accordingly. In the current analysis of the OTA scenarios, a 10 percent sustained oil price increase is assumed to reduce real output (GNP) by 0.4 percent after two years and by 0.2 percent after five years.

Table 4 contains results for the GNP losses as well as other economic impacts in both scenarios. For the above GNP elasticities (with respect to oil price), real GNP declines 5.0% below its baseline after two years and 2.0% below after five years in the disruption scenario. When accelerated oil replacement is combined with a disruption, these losses are lessened to 4.6% and 1.6%, respectively, for these two years.

Changes in Terms of Trade

The real GNP impacts measured by macroeconomic models represent changes in physical output. For example, in a highly stylized economy that imported only oil and produced only wheat, real GNP would be a statement of how many bushels of wheat produced minus how many barrels of oil imported. Relative prices would be used to aggregate bushels and barrels. Real GNP would change only if the amounts of wheat and oil were altered.

Higher oil prices also harm the economy in another way. Even if total physical production is not changed, the distribution of that output between foreigners and domestic residents is altered. The economy must now allocate more wheat towards paying for oil imports and retain less wheat for domestic consumption. Its real national income (in terms of its purchasing power over both wheat and imported oil) is reduced by the higher cost of oil. Due to the conventions of national income accounting, this reduction in real national income is not incorporated by the change in real GNP measured by macroeconomic models, although it can be calculated from other variables in these models showing the change in the prices of all goods purchased domestically as well as the prices of imports and exports.

Table 4: U.S. Economic Impacts

	Sustained Disruption		Disruption with Accel. Replacement	
	2nd	5th	2nd	5th
Percent Impact#:				
Output (GNP) Change	-5.0%	-2.0%	-4.6%	-1.6%
Terms of Trade Change				
from higher price	-1.3%	-1.0%	-1.2%	-0.9%
from lower imports	0.0%	0.0%	0.4%	0.7%
Oil Replacement Costs	0.0%	0.0%	-0.2%	-0.3%
Social Surplus Loss*	-1.3%	-1.0%	-1.0%	-0.5%
Real National Income** (total)	-6.3%	-3.0%	-5.6%	-2.1%
Billions of 1990$:				
Terms of Trade Chng				
from higher price	-75.0	-64.1	-69.3	-53.4
from lower imports	0.0	0.0	24.1	43.2
Oil replacement costs	0.0	0.0	-13.7	-19.7

#Percent below baseline. Percent estimates for terms of trade and oil replacement costs are based upon a $5.5 trillion economy.

*Sum of terms of trade and oil replacement effects.

**Sum of output and social surplus effects.

Under certain reasonable assumptions, this reduction in international purchasing power (sometimes called the terms of trade adjustment) can be approximated by multiplying the change in oil prices by the level of oil imports at full employment. The estimates in this analysis have been calculated from the oil price change and the average US oil import level in the baseline and disruption cases at full employment, i.e., without the GNP feedback effect. (Labor and capital inputs are held constant at their full-employment levels in this calculation. Hence, all of the estimated losses represent declines in the prices of these inputs rather than reductions in GNP measured in physical, i.e., real terms.) Terms of trade losses resulting from the disruption are less with than without the US oil replacement policy because both the oil price change and oil import levels are lower. In Table 4, these two effects almost offset each other in the fifth year of the oil replacement policy case, resulting in virtually no terms of trade losses in this scenario.

Oil Replacement Costs

The oil replacement policy requires capital and other inputs to be diverted from other sectors to reduce oil use beyond the level that would be selected by market participants responding to price alone. The reduction in national income caused by this shift is not incorporated in the earlier estimates of the real GNP loss, which were a function of oil price changes only.

A lower-bound estimate can be developed under the assumption that the oil-replacement policy selects only the most efficient technologies for implementing this additional reduction in oil use. The value of each barrel of replaced oil to market participants can be derived implicitly as the price that would be needed to induce substitution away from that barrel (as revealed by the US demand curve for oil). The total costs of the program would be the sum of these implicit prices, over the range of oil use (1.4 MMBD in the second year) being replaced. (These costs are calculated as one half the product of 0.51 billion barrels (1.4 MMBD times .365) and the change in price required to decrease oil consumption by 1.4 MMBD. The latter is derived from the US oil demand curve as revealed by the assumption about its price elasticity shown in Table 2.) Based upon this approach, the oil replacement policy would require an additional $ 13.7 B of national income be spent during the second year, and an additional $19.7 B in the fifth year, as shown in the bottom of Table 4. These costs could be substantially higher if the oil replacement program targetted investments that turned out to be more expensive. This assumption is a critical one for the analysis.

Changes in Real National Income

The losses for output (real GNP), terms of trade, and oil replacement have been reported separately in Table 4. The terms of trade and oil replacement costs are derived from an analysis of changes in social welfare defined as the sum of producer and consumer surplus. (See the appendix). Table 4 refers to the sum of the terms of trade and oil replacement costs as the change in social surplus.

The separation of GNP and social surplus losses follows the traditional approach of energy policy analysts in not aggregating what appear to be dissimilar costs. However, the sum of these components reveals what happens to real national income, and this sum is identified as such in the same table.

The reduction in real national income incorporates both the decline in physical output (e.g., bushels of wheat) as well as the decline in the country's international purchasing power (as reflected by the need to produce more output to continue importing the more expensive oil). Both effects reduce the country's ability to consume goods and services. In addition, the oil-replacement policy requires the substitution of labor and capital for oil, thereby lowering the productivity of these other inputs.

In the second year of the sustained disruption, real national income would be 6.3% lower than the baseline with the oil replacement policy and 5.6% lower without the policy. By the fifth year, real national income would be 3.0% lower with the policy and 2.1% lower without the policy. These results suggest that the policy could provide some modest benefits in both real output and real national income, although it should be emphasized that the policy has been represented in its most favorable form. We have attributed to the policy its largest impact on oil prices because it is assumed to displace only oil use that would not already be displaced by higher prices during a disruption. In addition, it is assumed that the policy targets only the most cost-effective opportunities for substitution away from oil that remain after the disruption. A more refined evaluation of the oil-replacement costs would require additional information on the cost effectiveness of different oil-replacement strategies as well as an estimate of how much of the oil replacement is induced by higher prices during the disruption and how much remains to be implemented even after the higher prices.

Impact on Oil Supplies and Demands

Although the analysis focuses on the impacts on oil prices and the U.S. economy, information about world and U.S. supply and demand in the two disruption scenarios can be helpful in interpreting the results. Oil market estimates consistent with the economic impacts discussed here are shown in Table 5. The oil supply and demand estimates include the GNP feedback effect.

TECHNICAL APPENDIX

This appendix documents the approach used to estimate the terms of trade and oil replacement costs. It also reports alternative impacts derived from different assumptions about the form of the elasticity.

Table 5: US and World Oil Supplies and Demands

	Sustained Disruption		Disruption with Accel. Replacement	
	2nd	5th	2nd	5th
US Consumption	13.3	14.1	12.3	11.9
US Production	7.7	7.3	7.8	7.6
US Imports	5.6	6.8	4.5	4.3
WOCA consumption	40.8	43.2	40.5	42.3
OPEC production	8.0	9.7	8.0	9.7
Non-OPEC output	32.6	33.2	32.3	32.4

Social Surplus Analysis

The estimates of the terms of trade and oil replacement costs are based upon the analysis of changes in social surplus, as represented in Figure 1. The domestic US price is represented along the vertical axis, while the quantity of US imports is represented along the horizontal axis.

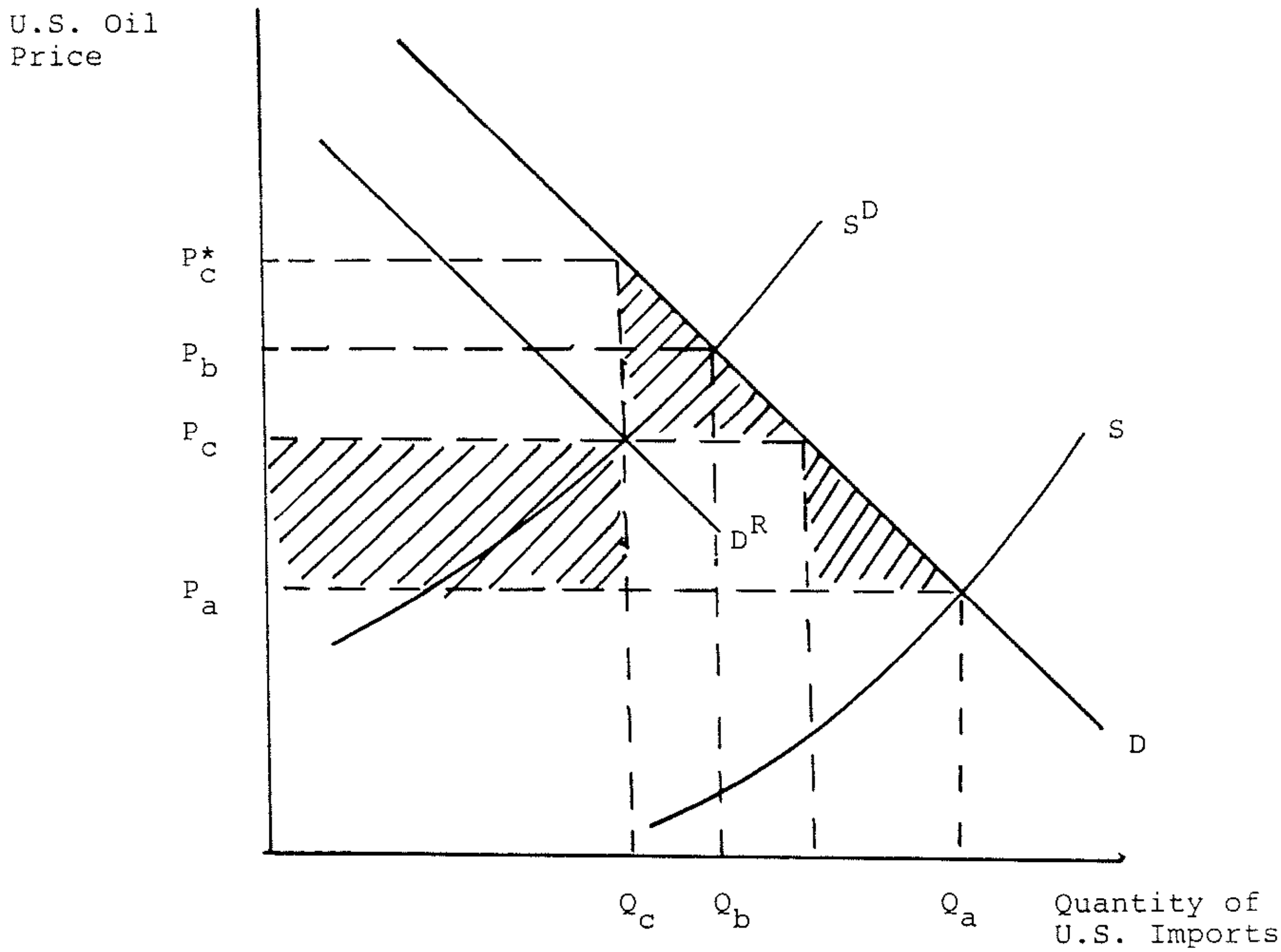
The US demand curve (D) shows total US consumption that is not met by domestic US production at different price levels. It slopes downward with world oil prices. Lower prices lead to more imports because firms substitute oil for other inputs, consumers buy more oil than other goods, and domestic U.S. suppliers produce less oil under these conditions.

The net import supply curve (S) represents the amount of oil available to the USA at different prices. The supply of US imports equals total world oil production outside the USA minus foreign consumption. This curve slopes upward with price. Higher prices lead to greater availability of imports because foreign firms and consumers buy less oil and foreign suppliers produce more oil under these conditions.

Baseline conditions occur at a price of Pa and an import level of Qa, where the supply of US imports match the demand for US imports. When oil markets are disrupted, the supply of US imports are reduced. Fewer imports are available at any price, as reflected in the leftward shift in that supply curve. As a result, oil prices rise from Pa to Pb, based upon world oil market parameters. US imports decline from Qa to Qb. Disruption losses are calculated from the formula given immediately below the figure.

The oil-replacement policy in this paper is analyzed like a disruption tariff. The US import demand curve is shifted inward to D(R), as the tariff reduces the net consumption of oil imports (through less consumption and more domestic production) for any world oil price. As a result, oil prices during the disruption do not need to increase as much as without the policy. They rise only to Pc rather than Pb, and oil imports fall to Qc.

Figure: Impact of Disruption and Oil Replacement Policy



Notes:

S,D	baseline supply and demand
S^D	disrupted supply
D^R	demand after oil replacement
P,Q	price and quantity in:
	baseline (a)
	after disruption (b)
	with replacement (c)
P*	implicit price imposed by policy

$$\text{Disruption Loss} = (P_a - P_b)(Q_a + Q_b)(.365/2)$$

$$\begin{aligned}\text{Loss with Replacement} = & (P_a - P_c)(Q_a + Q_c + 2.2)(.365/2) \\ & - (P_c - P_a)\ (2.2)\ (.365) \\ & + (P_c - P_c^*)(2.2)(.365/2)\end{aligned}$$

Losses for this case are calculated from the second formula below the figure. The first line represents the terms-of-trade losses from an oil price increase of Pc-Pa. The second line represents the gains from saving a price Pc on each of the 1.4 MMBD of oil imports that are replaced (or 3.0 MMBD in the fifth year). The third line represents the losses from replacing 1.4 MMBD beyond the level that would be optimal given a price Pc. The net losses are the sum of the three shaded areas in Figure 1.

Iso-Elastic Supply and Demand Curves

When the simulated disruptions are large, it may matter whether one assumes that price elasticities of supplies and demands are constant for all prices or whether they vary with the price level. In the analysis, different specifications of the oil supply and demand curves can lead to different estimates of the impacts, but the difference between scenarios, with and without the oil-replacement policy, is approximately the same.

A somewhat higher impact results when percent changes associated with large disruptions are represented as logarithmic differences. This alternative approach assumes that oil market functions have constant elasticities regardless of the price level; hence, the term "iso-elastic". The main results reported in this paper assume that elasticities increase with higher prices based upon the premise that oil-replacement activities intensify as oil's relative importance to the economy increases.

Table A.1 compares the results of the two specifications. The estimates indicate larger impacts for all scenarios with an assumption of constant elasticities, but a similar net impact--the difference between scenarios with and without the oil-replacement policy.

Appendix Table A.1
Impacts (%) with Iso-Elastic Functions
and Base Case Parameters

	Disruption with BAU Replacement		Disruption with Accel. Replacement	
	2nd	5th	2nd	5th
Oil Price Increase	347.0%	216.9%	282.9%	147.1%
Disrupted Price	$98.3	$69.7	$84.2	$54.4
Percent Impact# on:				
Output (GNP)	-5.8%	-2.3%	-5.2%	-1.8%
Terms of Trade				
from higher price	-2.9%	-2.1%	-2.7%	-1.6%
from lower imports	0.0%	0.0%	0.7%	1.0%
Oil Replacement Costs	0.0%	0.0%	-0.6%	-0.9%
Social Surplus Change*	-2.9%	-2.1%	-2.6%	-1.5%
Real National Income**	-8.7%	-4.4%	-7.8%	-3.3%

#Percent below baseline. Percent estimates for terms of trade and oil replacement costs are based upon a $5.5 trillion economy (1990) growing at 2.5% per year.

*Sum of terms of trade and oil replacement effects.

**Sum of output and social surplus effects.

Price Elasticity of Demand

Appendix Table A.2 contains estimates of the economic impacts under different assumptions about the price elasticity of demand. Both US and world responses are changed in these sensitivities.

A higher elasticity reduces the world oil price increase resulting from a disruption. Hence, both GNP and social surplus losses are reduced, often quite significantly.

GNP Loss Elasticity

Appendix Table A.3 contains estimates of the economic impacts under different assumptions about the GNP loss elasticity (with respect to oil prices). Both US and world responses are changed in these sensitivities.

The GNP loss elasticity barely affects the world oil price increase due to a disruption. (Higher elasticities dampen the oil price spike slightly, as a result of a lower GNP.) Hence, while this parameter value clearly influences the estimated GNP losses, it has almost no effect on the social surplus losses. The impact of the oil replacement policy (relative to the sustained disruption case) on real national income tends to be somewhat more favorable with a higher than a lower GNP loss elasticity.

Appendix Table A.2
Impacts (%) with Different
Price Elasticities of Demand

	0.1	0.2	0.3
Sustained Disruption			
Oil Price	146.3%	97.5%	73.1%
GNP	-2.9%	-2.0%	-1.5%
Social Surplus*	-1.7%	-1.0%	-0.7%
Real Income**	-4.6%	-3.0%	-2.2%
With Replacement			
Oil Price	118.8%	79.2%	59.4%
GNP	-2.4%	-1.6%	-1.2%
Social Surplus*	-1.3%	-0.5%	-0.2%
Real Income**	-3.7%	-2.1%	-1.4%

*Sum of terms of trade and oil replacement effects.

**Sum of output (GNP) and social surplus effects.

Appendix Table A.3
Impacts (%) with Different
GNP Loss Elasticities

	0.01	0.02	0.03
Sustained Disruption			
Oil Price	100.9%	97.5%	94.4%
GNP	-1.0%	-2.0%	-2.8%
Social Surplus*	-1.1%	-1.0%	-1.0%
Real Income**	-2.1%	-3.0%	-3.8%
With Replacement			
Oil Price	82.0%	79.2%	76.7%
GNP	-0.8%	-1.6%	-2.3%
Social Surplus*	-0.5%	-0.5%	-0.5%
Real Income**	-1.3%	-2.1%	-2.8%

*Sum of terms of trade and oil replacement effects.

**Sum of output (GNP) and social surplus effects.